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VACUUM SYSTEM FOR HYPERVELOCITY RAILGUN EXPERIMENTS

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VACUUM SYSTEM FOR HYPERVELOCITY RAILGUN EXPERIMENTS*

A. R. Susoeff

ABSTRACT

In order for railguns to achieve very high velocities it will be necessary to operate at reduced atmospheric pressure, perhaps even high vacuum. Use of railguns in a space environment will also be facilitated by successful vacuum operation. Equation of state research requires projectile impact on target prior to a bow shock wave necessitating high vacuum environment. The H Division/LLNL Railgun Project achieved successful high vacuum operation.

A modular, free-standing vacuum system was designed, fabricated and characterized to conduct experiments with single and multi-staged hypervelocity railguns. Operating environment for the experiments was in the low 10^{-6} torr pressure range, equivalent to the atmosphere at about 75/100 miles altitude. The first successful high vacuum region (i.e., low pressure side of the Paschen voltage breakdown curve) railgun experiments were performed with this apparatus. This report describes the vacuum system and its operating characteristics.

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SYSTEM COMPONENTS

The system includes: 1) individual flanged sections which have access ports to make external electrical connection to the pulsed power supply, electrical diagnostics and allow attachment of a first stage injector which can initially accelerate the projectile using a 5000 psig gas reservoir, 2) a diagnostic section in which flash x-ray, laser trigger and time-of-impact detection systems were located, 3) a catch tank section to collect shrapnel generated during projectile impact, and 4) pumps, valves and gauges to generate, control and characterize the vacuum. Figure 1 is a system block diagram and Figure 2 is a side view of the system layout. Various feedthroughs allow experimental data to be acquired and samples of residual gases to be collected for analysis.

SYSTEM DESIGN

Chamber sections were weldments fabricated from 6061-T6 aluminum. Feedthrough flanges and cover plates were made of 304 stainless steel or 6061-T6 aluminum. Electrically insulating material such as fiberglass reinforced epoxy (N.E.M.A. G-10), acrylic and polycarbonate materials were used to fabricate diagnostic and high-current bus feedthroughs. Fluoroelastomer O-ring seals were used at all flange connections. A custom feedthrough seal, shown in Figure 3, was designed for the current carrying bus bars. It allowed about 0.1 inch movement in any direction while still maintaining chamber vacuum and electrical isolation. The seal was molded of two part catalyzed silicone rubber. Standard practice of providing bleed holes or leak paths for gases trapped in the railgun during assembly was strictly adhered to. The internal roller bearing supports which were used to support the railgun and facilitate its movement in and out of the chamber, had one grease shield removed, were degreased and repacked with molybdenum disulfide powder. All exposed current carrying surfaces, about 100 in^2 area, were coated with catalyzed silicone rubber to prevent spurious arcing.

PUMPING

Rough evacuation of the chamber was done through a 104 cfm Roots type pump backed by a 30 cfm mechanical pump. High vacuum was generated by using a combination of a 450 ℓ/s turbomolecular pump and a 1500 ℓ/s cryogenic pump. Valves in the pumping circuit allowed access or bypass of pumping components. Pumpdown sequences were employed to minimize back-streaming of pump oil into the chamber. Roughing of the cryopump was done through a zeolite adsorber trap. All pumps and sensitive gauges were isolated during the firing of an experiment.

LEAK TESTING

Individual components were certified to have leak rates of less than 1×10^{-7} torr liters/sec. Using a combination of helium spray, tracer probe and modified hood techniques, a mass spectrometer helium leak detector with a sensitivity of 1.2×10^{-9} atm/cc/sec was used for leak testing the assembled system.

PRESSURE MEASUREMENT

A Bourdon compound gauge was used to monitor the roughing process. Thermal conductivity gauges such as Pirani and thermocouple types were used to monitor medium range vacuum. High vacuum was measured using a Bayard-Alpert ionization gauge and a cold cathode discharge gauge.

Typically, ion gauges placed about 5 meters apart on the chamber showed no difference in pressure once the lower end of the 10^{-6} torr range was reached.

CHAMBER AND PUMPING CHARACTERISTICS

The empty chamber volume was about 1000 liters. Installation of a 5.2 meter railgun displaced about 200 liters of volume. Pumpdown time using the mechanical/roots/turbo combination was typically two hours to reach the low 10^{-5} torr range.

The 1500 ℓ/s cryopump took about two hours to reach maximum pumping efficiency and when valved into the chamber (turbo pump valved out) would reduce the pressure from the low 10^{-5} torr region to low 10^{-6} torr in about two hours.

Since the railgun was pumped from the muzzle only, the breech pressure was higher due to the outgassing of the railgun materials and low conductance of the long length small bore. Using the region of molecular flow as a boundary, the formula for conductance in liters per seconds is:

$$C = 12.1 \frac{d^3}{L}$$

Where d is the bore diameter and L is the bore length in centimeters. The 1.6 meter long railgun with a 1 meter long injector and 1.3 centimeter bore resulted in a conductance of about 0.17 ℓ/s at the breech and 0.10 ℓ/s for the entire length including the injector. The 5.2 meter railgun with a 1.1 centimeter bore had conductances of 0.030 ℓ/s and 0.026 ℓ/s respectively. Figures 4 and 5 show the pump down rates at each end of the launcher.

A series of voltage breakdown tests were conducted to determine the required vacuum to avoid breakdown at voltages up to 5.5 KV. The maximum bank voltage was 5 KV. The results are shown in Figure 6.

In order to minimize debris and soot back-filling into the pumping equipment all pumping was isolated prior to firing. Shot debris and loose soot were removed from inside the chamber after each experiment. The 5.2 meter long railgun experiments used approximately 300 liters (10.6 cubic feet) of helium gas to preaccelerate the projectile and resulted in a chamber pressure rise to about 250 torr after an experiment. The chamber was back-filled with N_2 gas to bring it up to atmospheric pressure. Over a period of some 130 electrically powered experiments the system pumpdown and pressure rise rates remained stable. Typical rise rates are shown in Figure 7. Rates of rise in the chamber were assumed to be due to the outgassing of railgun materials and virtual leaks. The rate of pressure increase was slow enough for this vacuum system to allow at least a 20 second window to perform an experiment on the high vacuum side of Paschens curve.

SUMMARY

Successful railgun experiments using voltages of up to 5 KV in an environment equivalent to the atmosphere at about 75/100 miles altitude have been conducted at Lawrence Livermore National Laboratory. These experiments were contained in a free-standing, modular vacuum system.

ACKNOWLEDGMENTS

Discussions involving system parameters and specifications were done with Ron Hawke. Glenn Newman interfaced the electronic and electrical controller modules to the vacuum system and coordinated the necessary fabrications.

The technical assistance of Gary Devine and the helpful assistance of Dick Bast, Pete Bowen, Mike Casey, Mel Clary, Mike Niblack, Doug Ravizza, Ron Silva, Norm Stewart and Don Turner is greatly appreciated.

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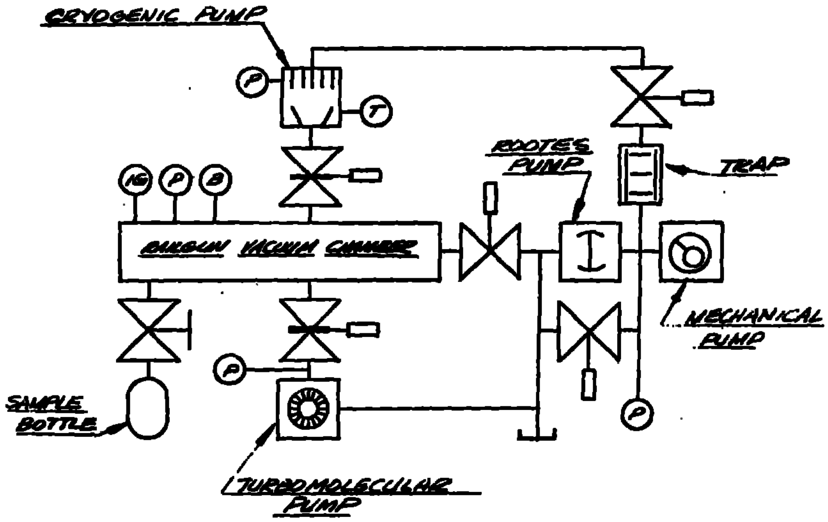

Figure 1 Railgun Vacuum System - Block Diagram

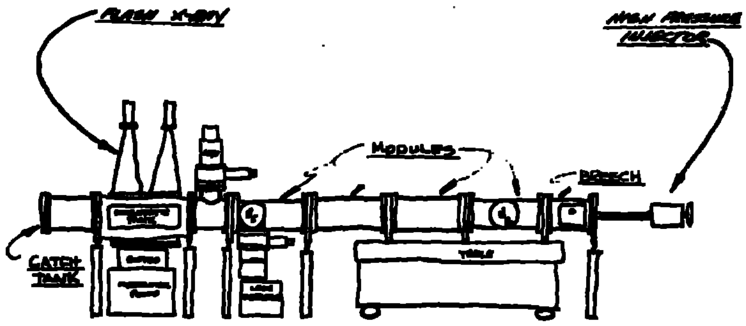

Figure 2 Railgun Vacuum System Layout

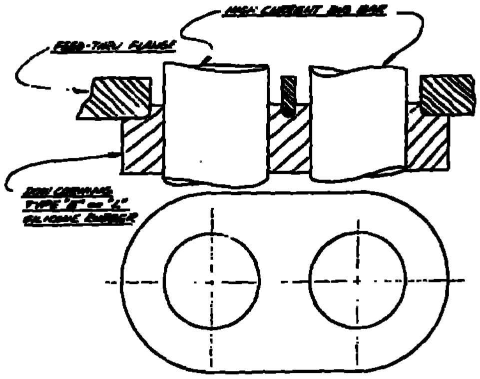

Figure 3 Bus Bar Feedthrough Seal

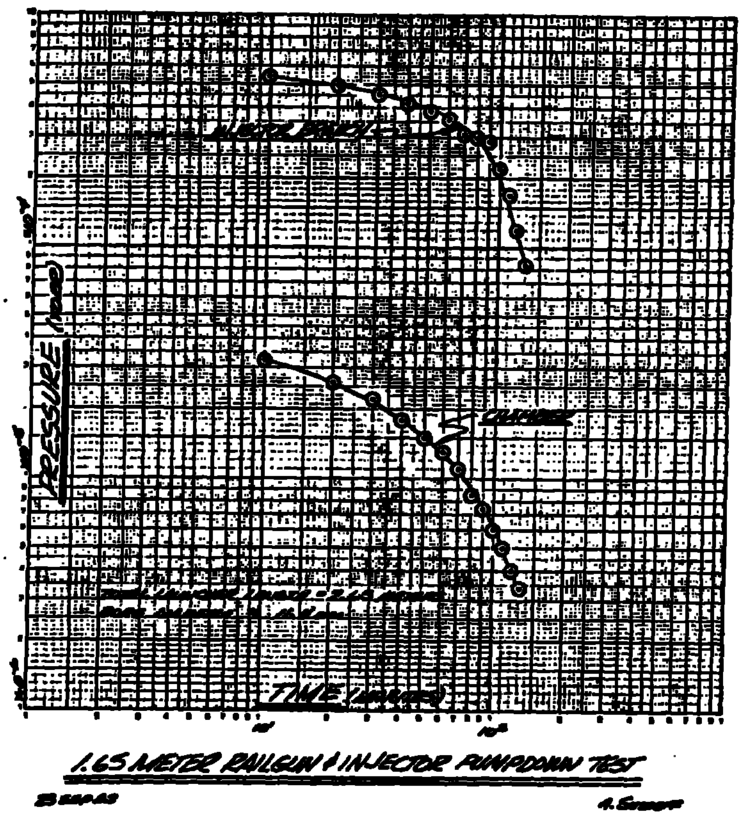

Figure 4 Pumpdown Pressure: Injector Bore and Chamber vs. Time - 1.65 Meter Railgun

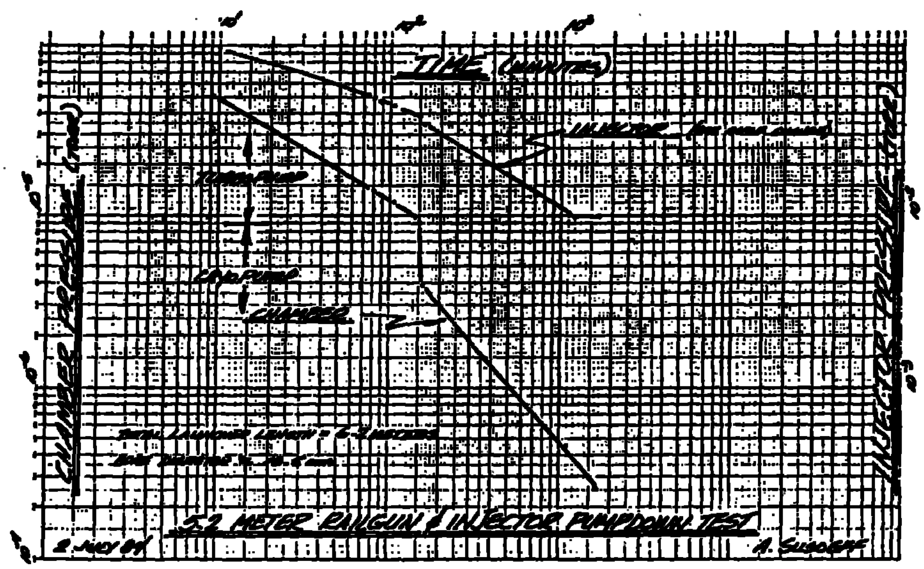

Figure 5 Pumpdown Pressure: Injector Bore and Chamber Pressure vs. Time - 5.2 Meter Railgun

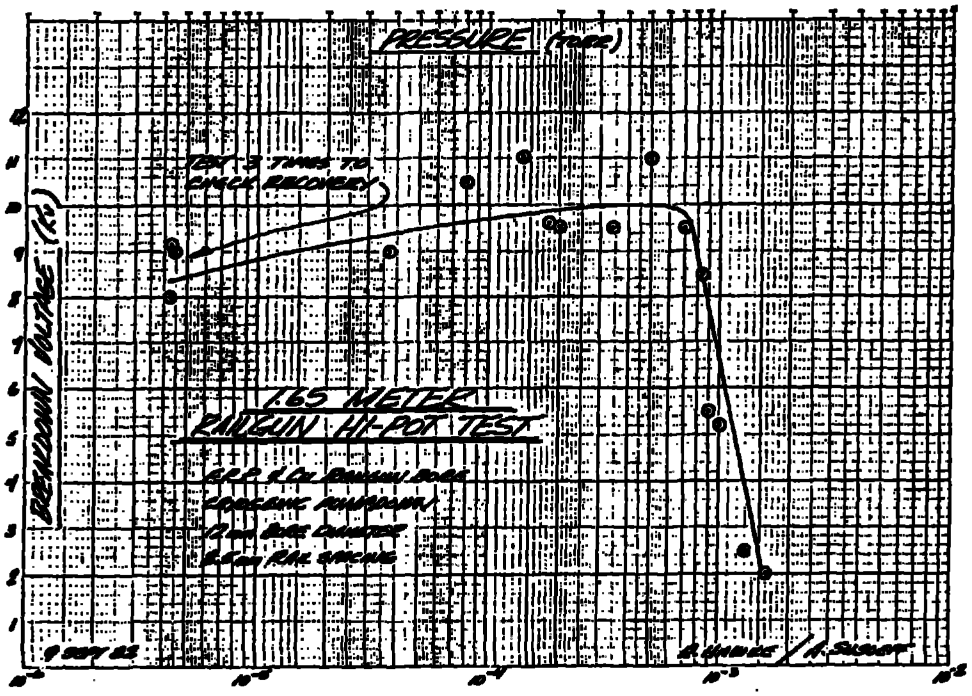

Figure 6 Breakdown Voltage vs. Railgun Bore Pressure on High Vacuum Side of Paschens Breakdown - 1.65 Meter Railgun

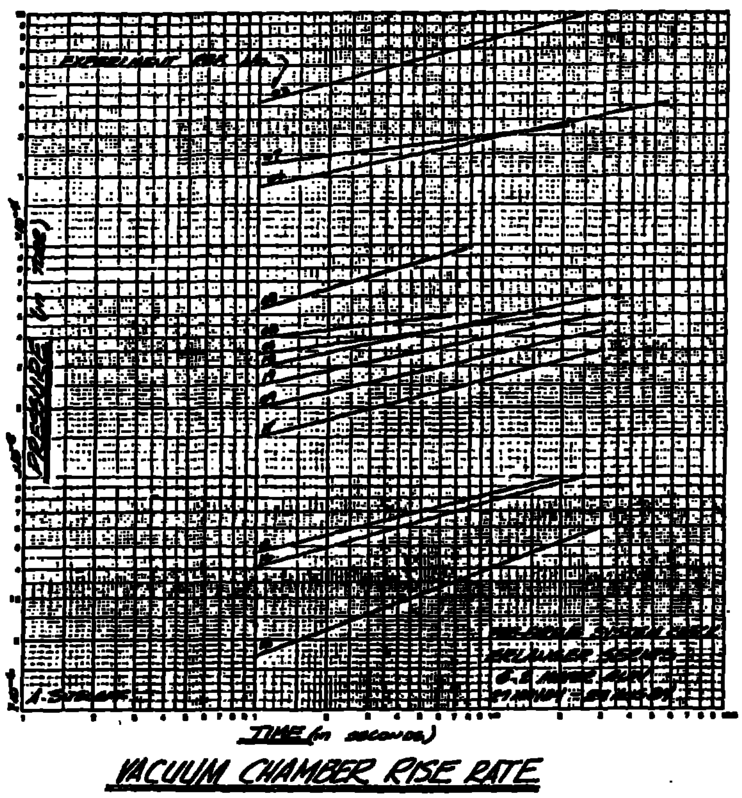

Figure 7 Vacuum Chamber Rate of Chamber Pressure Rise - 5.2 Meter Railgun